Instant Advertising in Mobile Peer-to-Peer Networks

Zaiben Chen†, Heng Tao Shen†, Quanqing Xu‡, Xiaofang Zhou†

†School of Information Technology & Electrical Engineering, University of Queensland, Australia

‡Department of Computer Science, Peking University, Beijing, China

{zaiben,shenht,zxf}@itee.uq.edu.au, {xqq}@net.pku.edu.cn

***Abstract*— To explore the benefit of advertising instant and location-aware commercials that can not be effectively promoted by traditional medium like TV program and Internet, we propose in this paper a solution for disseminating instant advertisements to users within the area of interest through a Mobile Peer-to-Peer Network. This is a new application scenario, and we devise an opportunistic gossiping model for advertisement propagation with spatial and temporal constraints. As bandwidth and computational resources are limited in a wireless environment, two optimization mechanisms utilizing distance and velocity information are provided for reducing redundant advertising messages. User interest is also considered as another critical factor in adjusting the advertisement propagation model, and we adopt the FM algorithm to achieve efficient counting of distinct users' interests. Finally, we study the performance of our solution through simulation in NS-2. Compared with the naive flooding method, our approach achieves high quality delivery rate while reducing the number of messages by nearly an order of magnitude.**

I. INTRODUCTION

Advertising plays a very important role in our daily life and it provides a huge marketplace. From TV program, Internet or radio, we can find various advertisements everyday. However, we rarely see those instant and highly location-related advertisements (ads) such as petrol price update from a nearby petrol station in the morning, discount information on fruits in a close Wal-Mart supermarket in the afternoon, and garage sale in the suburb we live in. For this kind of *instant ads* that happen and change quickly and timely in a spatial area, it is not cost-efficient to advertise them on traditional medium like TV program and Internet, or even when you find those ads from TV program, they are probably out of date as they are only available for a quite short period (e.g. petrol price may has been updated). Take the supermarket as another example, we usually come across discounted goods from time to time but hardly be able to find out what will be discounted without walking into the supermarket. Nevertheless, this kind of ads are very attractive to many consumers since most of us hope to find something cheap and good easily in our daily life. Therefore, we propose in this paper a solution for disseminating this kind of ads in our daily life through a Mobile Peer-to-Peer Network. A Mobile Peer-to-Peer Network is an application-driven network consisting of a set of mobile devices (e.g. PDAs, vehicles) that communicate over short-range by bandwidth-constrained wireless links. We consider a Mobile Peer-to-Peer Network as the advertising medium because of the following temporal and spatial characteristics of instant ads to be advertised:

(1)Short-term. As mentioned above, the availability of instant ads would elapse quite quickly and then becomes expired soon. Compared with TV program and Internet, mobile devices such as handsets and vehicular wireless devices are always with users, thus they can provide timely sharing and access to instant ads and notify users as soon as the ads are issued.

(2)Location-aware. Notice that the information to be advertised typically belongs to a specified location/area rather than a device. For example, a petrol price ad issued from the petrol station at Queen's St is only meaningful to those drivers on or approaching Queen's St, which means the ad is only of interest in the vicinity of the issuing location. A mobile p2p network is a suitable means for disseminating this kind of highly location-aware ads to mobile devices within a geographical area.

Considering the aforementioned two characteristics, we envision such an example scenario as shown in figure 1. Firstly, a supermarket employee issues an advertisement of goods provided by the shop through handset, and then the ad is propagated to vehicles and pedestrians equipped with mobile devices within the nearby area (the circular shadow area in figure 1) hop by hop for a duration. Those who are passing through the area will be notified of the ad, and interested users may stop by and purchase what they need. Obviously, the cost of this kind of advertising is extremely low as peers communicate by short-range wireless link directly, while it may attract many potential buyers, who are also benefited from the ad since they can find goods at special prices easily. Notice that there could be many different shops, individuals issuing ads at different places, and the ad we mention here includes but not limited to commercial information. Disseminating traffic condition information, finding free parking places, emergency response and so on [1][2][3][4] could also be referred to as more general type of information advertising.

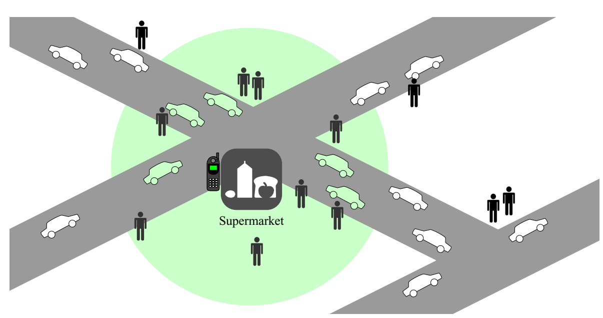


Fig. 1. Application scenario

Since there is no central server available and it is very expensive to maintain a network topology in highly vulnerable mobile environment, all peers within the specified advertising area have to cooperate together to maintain the advertisement in an unstructured way, and try to deliver the advertisement to new coming peers. Therefore, different from traditional query-oriented dissemination [5] and publish/subscribe dissemination models [6][7][8] in which users retrieve information from middle-ware service based on their subscriptions and only interest-matched data is disseminated to subscribers, the problem in our application is essentially how to disseminate a piece of advertisement to as many users as possible within a specified advertising area. Users may choose not to display an advertisement of no interest to avoid annoying advertisements, but if they want to receive interesting ones, they have to take part in relaying and maintaining the advertisement if they are within the corresponding advertising area for a short duration until they leave, which is very similar to the incentive mechanism in a peer-to-peer system.

Intuitively, periodical flooding is a simple way to advertise information although it causes excessive messages. In our solution, to alleviate the network traffic while achieving efficient advertising, we devise an opportunistic gossiping model for propagating and maintaining an advertisement within a specified spatial area (called advertising area). In this model, mobile peers periodically gossip with their neighbors to forward the advertisement with a probability determined by location and age information while guaranteeing the advertisement can exist in the advertising area for a duration and most peers that passing through the advertising area will receive the advertisement sooner or later. Since the number of messages generated by pure gossiping is comparable to flooding, we design two types of optimization mechanisms that utilize distance and velocity information for reducing redundant advertisement messages. By properly adjusting the distribution of gossiping probability within the advertising area as well as the scheduled time of gossiping, the network traffic is decreased significantly. As the popularity of ads are different, user interest is also considered in our model for ads ranking to adjust parameters of the advertising model and consequently affects how long an advertisement can survive and how large the spatial area it can reach. Besides, FM Sketch [9] is adopted in the ranking approach for counting the number of distinct users with the same interest, achieving efficient use of memory space and bandwidth. To sum up, we make the following main contributions:

- We introduce a new application scenario for efficient instant advertising in a Mobile Peer-to-Peer Network. It is applicable to many emerging applications in commercial promotion, traffic estimation, emergence services and so on, where timely and location-based information sharing is needed.
- We present an opportunistic gossiping model for disseminating instant ads, including a probability function for determining advertisement forwarding probability at different locations and a shrinking mechanism for adjusting the advertising area by age information.
- We propose two optimization approaches for the opportunistic gossiping model to reduce the number of advertisement messages significantly. In the first approach, velocity constraint is integrated into the probability function to reduce the gossip area. In the second approach, both distance and velocity information are taken into account to postpone the scheduled gossiping time.
- We propose an advertisement ranking function designed to reflect the popularity of an advertisement. An approach to acquire advertisement popularity based on FM algorithm is introduced, as well as algorithms for enlarging the advertising area and survival time of popular advertisements according to their advertisement popularity.
- We conduct extensive simulations to prove that the quality of our optimized model is as good as flooding in term of advertisement delivery rate while improves the performance significantly in term of the number of messages.

The remainder of the paper is organized as follows. In section II, related work is presented. Advertising model and optimization methods as well as ranking algorithms are introduced in section III. Simulation results are discussed in section IV and we draw a conclusion in section V.

II. Related Work

Instant advertising in a Mobile Peer-to-Peer Network is a completely new application, however there are some relative work from which we got the inspiration. Opportunistic Resource Exchange [10] for disseminating real-time location-specific information (e.g. parking spaces, traffic conditions) in inter-vehicle ad-hoc networks could be considered as the first to raise such kind of data dissemination issue. To limit the distribution of a resource to a bounded spatial area for a period, the relevance of resource that decays linearly with age of the resource and distance from the generating location is calculated, and only the most relevant resources are kept in memory and exchanged when vehicles encounter with each other. The Resource Relevance model is further discussed in [11] and a mathematical model for resource propagation is proposed. To some extent, our solution is similar to the Opportunistic Resource Exchange model, but we use a different propagation manner (gossiping *vs* exchange at encounter) and different probability functions because of different application requirements which we will present in the next section.

Resource Relevance model simply guarantees the short-term and location-aware characteristics of resource for exchange, nonetheless it does not take into account whether the resource is of interest. Therefore, in [1] and [4], the authors develop a ranking algorithm and each resource is ranked according to user queries. The more times a resource matches queries, the higher its rank will be, and only the top ranked resources are forwarded. In this method, user queries need to be broadcasted to neighbors at encounter as well and queries from neighbors are also randomly selected to be forwarded. However, the forwarding only depends on the rank of resource, and thus the spatial and temporal characteristics of resource are not preserved anymore, which may lead a resource to be disseminated to the whole network for a long period even if it is only available in a small area and for a short duration. In our work, we aim to disseminate advertisements considering user interest while still maintaining the spatial and temporal characteristics. Besides, reducing the total number of messages is another focus of our work which is not considered in [1][4][10][11].

Another work in [3] is designed for discovering free parking places by broadcasting resources. Static parking automats and vehicles cooperate together to maintain a grid-tree structure topology for aggregating and spreading parking information. However, our application is not limited to finding parking slots and there is no static peer assumed to be available. In [2], an function-driven dissemination mechanism is devised for transferring traffic conditions to target regions in inter-vehicular networks. Several diffusion algorithms are proposed in the paper, and propagation function is integrated for determining the direction of diffusion. Yet, the diffusion algorithms are actually geo-routing schemes to some extent and are not applicable to our application.

User interest is an important factor in adjusting the advertising model. In [1] and [4] only a fraction of randomly chose user queries are considered, which may decreases the accuracy in calculating the rank of a resource. To estimate the number of different users that are interested in the same advertisement without duplicate counting, we got inspiration from [12] and [13] which provide solutions for data aggregation such as calculating the SUM of readings in wireless sensor networks. Our solution is to apply FM Algorithm [9] which is a bitmap-based probabilistic counting algorithm for estimating the number of distinct elements in a large collection.

III. Instant Advertising Model

A. Overview

In our advertising model, advertisements are disseminated over a Mobile Peer-to-Peer Network, within which each mobile peer could be a vehicle or pedestrian equipped with a mobile device. Each peer moves in the advertising area will be notified of the advertisement and takes part in maintaining the advertisement with other peers. These peers communicate by short-range wireless transmission (e.g. IEEE 802.11, Bluetooth) and we assume that all peers' geographic position could be acquired by global positioning system (GPS) or other type of positioning services [14].

The *Advertising Area* mentioned here is the area that an advertisement message can be spread to, which is a circular area with a pre-set radius *R* (e.g. 1000 meters) centered at the location where the advertisement is issued (*i.e. issuing location*). The survival time of an advertisement is also initially limited to a duration *D* (e.g. one hour). Both *R* and *D* are propagation parameters of our advertising model, which reflect the spatial and temporal characteristics of an advertisement respectively. These two parameters are embedded as fields in the advertisement message, and we will show how they are increased and decay respectively when an advertisement is being propagated. Besides, the *issuing time* and the coordinate of *issuing location* are also embedded in the message for deriving the age and distance information. To precisely reflect the characteristics of instant advertisements, the propagation model should follow the following requirements:

1) An advertisement is densely distributed within the corresponding advertising area, contrast to a very sparse distribution outside the advertising area, as we make the assumption that an advertisement is only of interest in the vicinity of issuing location.
2) The advertising area shrinks with time elapsing and finally the advertisement will be eliminated, since an instant advertisement is available only for a short duration.
3) The size of advertising area and survival time of an advertisement could be adjusted on the fly according to its popularity measured by user interest so that more popular advertisements can benefit more users.

We use a modified gossiping scheme [15][16] to propagate advertisements. Other than selecting one or a subset of neighbors to forward a 'gossip', each peer decides whether to forward an advertisement with a probability *P* determined by the age of the advertisement and how far the peer is from the issuing location. The broadcast nature of wireless transmission is also exploited to transfer an advertisement to all neighbor peers by one single message. Every time instance $\triangle t$, which is called a Gossiping Round, each peer broadcasts advertisements it holds to all its neighbors with the corresponding probability. All peers work asynchronously and the gossiping process is always active in order to maintain the advertisement in the network for a period. Notice that advertising areas of different advertisements may overlap, and a peer may carry more than one advertisement. Therefore, all received advertisements are sorted by forwarding probability and stored in cache. If the number of received advertisements exceeds a threshold, those with low probabilities will be discarded. So actually it is similar to a *Store & Forward* [17][18][2] strategy that greatly improves the performance of data delivery when in sparse network. In the next subsections, we will present how to compute the forwarding probability *P*, how to reduce redundant messages as well as the interest-based ranking algorithm. Table I shows a list of notations used in this paper.

B. Restricted Flooding

A simple and effectual way to disseminate instant advertisements to surrounding mobile peers is to flood messages with spatial range constraint. This method is used as the baseline approach for comparison in our experiments. The issuer peer broadcasts the advertisement with radius R embedded in the message to its neighbors periodically, and then each neighbor peer that receives the message relays it further until the message is outside the advertising area limited by R. The broadcasting cycle is set to be the Round Time $\triangle t$, and R will be decreased gradually by the issuer peer as time elapses. The advantage of this method is the simplicity and stability in maintaining the advertisement message, as well as high

TABLE I

A LIST OF NOTATIONS

Notation	Description
P	Forwarding probability
R	The initial radius of an advertising area
D	The initial duration of an advertisement
α, β	Tuning parameters $\in (0, 1)$
R_t	The radius of an advertising area at time t
t	The age of an advertisement
d	The distance from the issuing location
$\triangle t$	Gossiping round time
ρ	The average density of mobile peers
V_{max}	The maximum speed of mobile peers
DIS	The width of the annular region defined in optimized gossiping-1
r	The transmission range of wireless channel

delivery rate in un-sparse network. However, the number of messages is expected to be $O(\rho\pi R^2)$ per $\triangle t$ where ρ is the average density of mobile peers in the area, and the issuer peer has to be always on-line during the whole advertising period D.

C. Opportunistic Gossiping

To avoid relying on a central issuer peer and to improve the robustness of the system, we devise an *Opportunistic Gossiping* model, in which advertisements are maintained by all mobile peers cooperatively within the advertising area in a gossiping way. As described previously, peers broadcast each advertisement they hold in cache to all neighbors within the transmission range at a probability P every *Gossiping Round Time* $\triangle t$. In such a way, the issuer peer could issue an advertisement to neighbor peers and then go off-line, after which the advertisement is gossiped around in the nearby area. To achieve dense distribution of an advertisement only within the specified advertising area, we propose a probability function for determining the forwarding probability as specified in formula 1, in which the probability of whether to forward an advertisement to neighbors is determined by the distance d from the location where the advertisement is generated. The farther the current peer is from the issuing location, the less the probability of forwarding the advertisement is.

$$P = \begin{cases} 1 - \alpha^{R_t + 1 - d} & (\text{if } d \leq R_t\ ) \\ (1-\alpha)\alpha^{d - R_t} & (d > R_t) \end{cases} \quad (1)$$

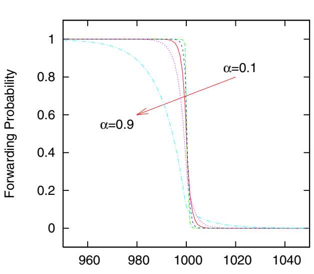


Fig. 2. Probability

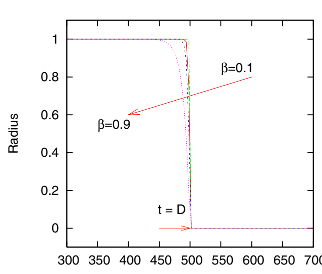


Fig. 3. Radius

In formula 1, $0 < \alpha < 1$ is the tuning parameter determining how fast P drops with distance, and R_t is the radius of the advertising area at age t. Intuitively, higher α leads to lower P since a faster drop in probability, and we will show how to choose a proper α in our experiment section. R_t is derived from formula 2 and it shrinks as age grows. The distribution of forwarding probability determined by formula 1 is shown in figure 2. P decreases slowly if $d < R_t$ as the distance increases, and drops drastically when d is close to R_t, and approximates to 0 when d is larger than R_t. Thus, the opportunity of advertisement forwarding is much higher in the advertising area than that outside the area, which implies a much denser distribution of advertisement messages within the advertising area. By doing so, requirement 1) is guaranteed theoretically, and an advertisement can be 'gossiped' to every peer if the peer's distance from the issuing location is less than R_t. Consequently, the issuer peer is no longer required to be on-line all the time like that in *Restricted Flooding*, which means the issuer can simply broadcast an advertisement to peers nearby and then go off-line.

Since P is also sensitive to the age t of an advertisement which indicates how long the advertisement has existed for from the issuing time, and old advertisements tend to be of no interest and expired, the advertising area is expected to shrink with the age of an advertisement rising as stated in requirement 2). Formula 2 shows how R_t decreases by t.

$$R_t = \begin{cases} (1 - \beta^{D-t})R & (\text{if } t \leq D\ ) \\ 0 & (t > D) \end{cases} \quad (2)$$

In this formula, R is the initial value of radius when the advertisement is issued. $\beta \in (0, 1)$ is the decay parameter determining how fast R_t drops. This formula is a little similar to formula 1, but has a different drop rate. Before the advertisement expires ($t < D$), the radius of advertising area keeps comparatively stable ($R_t \approx R$). Once the age becomes close to the initial advertising duration D, the radius is dramatically reduced to a very small value and reaches 0 when $t = D$. Consequently the advertising area fades away, which leads the corresponding advertisement to expire and then be eliminated. This setting makes sure that those instant advertisements can only exist in the network for a pre-set short duration. Figure 2 and figure 3 illustrate how P and R_t decay as d and t increase respectively with $R = 1000, D = 500$ and different α, β from 0.1 to 0.9.

Based on formula 1 and 2, we develop algorithm 1 and 2 to deal with a received advertisement and 'gossip' advertisements at each gossiping round. First of all, when a peer receives an advertisement message, it checks whether the advertisement is already in local cache (an advertisement is identified by the issuer's MAC address plus ID). If the advertisement is a new one, it will be inserted to cache and then the cache will be refreshed to keep only the advertisements with top-k (e.g. k=10) forwarding probabilities. At each gossiping round, all advertisements in cache are broadcasted according to their corresponding probabilities respectively, and the scheduled time for the next gossiping round is reset.

Algorithm 1: Receiving advertisement

```
when receive an advertisement ad {
if ad exists in cache then
    discard ad;
else
    insert ad to cache;
    if cache.size > k then
        refresh all entries probabilities;
        drop the entry with the least probability;
}
```

Algorithm 2: Gossiping advertisement

```
when current time = scheduled time {
if cache.size >0 then
    refresh all entries probabilities;
    broadcast each entry with the corresponding probability;
    scheduled time ← current time + △t
}
```

The most advantage of this pure gossiping model is that advertisements are maintained ad-hocly without the aid of a central peer (issuer peer), and it achieves high advertisement delivery rate no matter in sparse or dense network (shown in the experiment section). However, the number of messages per gossiping round is $O(\int_0^\infty P(l)\rho 2\pi l \cdot dl)$, which is comparable to $O(\rho\pi R^2)$ since $P(l)$ $(0 \leq l < R)$ could be close to 1, and therefore pure gossiping model does not improve too much in term of message number compared with the *Restricted Flooding* scheme.

D. Optimized Mechanisms

Pure *Opportunistic Gossiping* model involves too many messages comparable to the flooding approach. Hence, in this subsection, we provide two mechanisms to optimize the *Opportunistic Gossiping* model, trying to reduce redundant messages while still guaranteeing every peer that passes through the advertising area still has high opportunity in receiving the corresponding advertisement. To achieve that, we consider distance and velocity factors to restrict the area of gossiping with high probability, and carefully postpone the scheduled time for the next gossiping to avoid unnecessary gossiping. Consequently the number of gossiping is reduced and thus network traffic can be significantly improved.

(1) ***Optimized Gossiping-1***

We observe that the distance that a mobile peer can move in a $\triangle t$ interval is at most $DIS = V_{max} \times \triangle t$. This is obvious since the maximal speed V_{max} constrains the range a peer can move to. Based on this spatial constraint, within a round time $\triangle t$, every peer that newly enters the advertising area must be within the annular region of radius $R - DIS$ centered at the issuing location and of width DIS, as shown by the shadow part in figure 4. Therefore, except for the first time that an advertisement spreads from the issuing location outwards after being generated, peers within the circular area with a radius $R - DIS$ have no need to forward the advertisement as frequently as those within the annular region, because all newly entered peers would probably be notified of the advertisement while they are passing through the annular region if the distribution of peers is dense enough. Nevertheless, it is not reasonable to assume that peers within the annular region are always dense enough. Thus, in case that mobile peers do not receive the advertisement when passing the annular region because of sparse distribution of peers, we could extend DIS to a larger value in implementation to improve the opportunity of advertisement delivery to new peers. However, the model restores to pure gossiping model gradually with DIS rising close to R. So we need a trade-off and we will discuss this value in the experiment part.

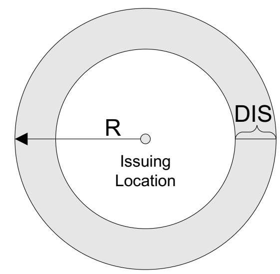


Fig. 4. Velocity constraint

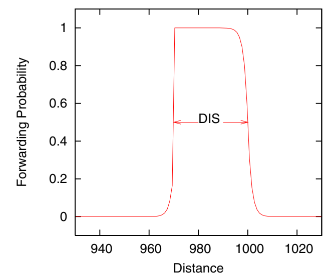


Fig. 5. Probability

According to the regions divided by the circle of radius $R - DIS$, the *Opportunistic Gossiping* model is modified to release those peers in the central part ($radius < R - DIS$) of the advertising area from frequent advertisement gossiping as shown in formula 3. Figure 5 illustrates how the forwarding probability changes according to the distance d (we set $R = 1000, DIS = 30$ in this case). It can be seen that only peers within the annular region are active in advertisement gossiping with high probability, and thus the number of advertising messages is reduced.

$$P = \begin{cases} 1 - \alpha^{R+1-d} & (\text{if } R - DIS \leq d \leq R\ ) \\ (1-\alpha)\alpha^{d-R} & (d > R) \\ (1-\alpha^{1+DIS})\alpha^{R-DIS-d} & (d < R - DIS\ ) \end{cases} \tag{3}$$

As a result, the number of messages per gossiping round is expected to be approximately $O(\rho\pi(2R \times DIS - DIS^2))$ theoretically, at the price of possible drop in the number of successful advertisement delivery to new peers since they may miss receiving the advertisement when going through the annular region, and we also notice that this mechanism is not applicable to the flooding method since it blocks the central peer from broadcasting advertisements outwards.

(2) ***Optimized Gossiping-2***

In pure gossiping model, many gossiping rounds are evitable since a peer has no need to broadcast an advertisement to its neighbors again and again if they have already known about the advertisement. We notice that if two peers are very close to each other, which means the areas covered by their transmission ranges (called transmission area) overlap approximately, these two peers do not need to both broadcast the same advertisement one after another immediately, because their neighbors are almost the same. A peer could soundly assume that almost all its neighbors have already got the advertisement to be broadcasted after a very close neighbor peer broadcasts the same advertisement. Therefore, when a peer B overhears that another peer A nearby is broadcasting an advertisement that is also in B's cache, then B can postpone the scheduled time for broadcasting the advertisement. The larger overlapped transmission area A and B share, the longer time the next scheduled gossiping could be put back. Besides, the direction of a peer's velocity, which can be derived from too consecutive recorded locations, is another factor affecting the next scheduled time. Still consider the above example, if B is moving towards A, the chance that A and B's transmission areas keep almost overlapping with each other is high and hence larger interval could be added to the next scheduled time. We develop formula 4 to describe how to determine the new scheduled time T_{new}. Here, T_{cur} is the current scheduled time for the next gossiping, and p denotes the percentage of the overlapped region of A and B's transmission areas to B's transmission area, and $\theta \in [0, \pi]$ is the angle between B's motion direction $\overrightarrow{V}$ and the line $\overrightarrow{BA}$ (see figure 6).

$$T_{new} = T_{cur} + \triangle t \times e^{p-1} p \cos \frac{\theta}{2} \quad (4)$$

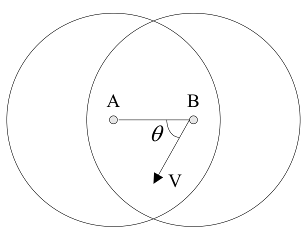


Fig. 6. Illustration of A and B

The range of p is $[\frac{2}{3} - \frac{\sqrt{3}}{2\pi}, 1]$ since when two peers are within each other's transmission range, the distance between them is at most r (transmission range), and the overlapped part of the two communication areas with radius r is $\frac{2\pi r^2}{3} - \frac{\sqrt{3}r^2}{2}$. As p increases and θ decreases, the *interval*$=\triangle t \times e^{p-1} p \cos \frac{\theta}{2}$ that to be added to the scheduled time for next gossiping rises quickly. Therefore, overhearing the same advertisement from a closer neighbor would cause a much greater delay. In a dense network a peer may receive the same advertisement from many different neighbors continuously and hence it could postpone the next gossiping time many times and experience long waiting time from one gossiping round until the next one. As a consequence, many unnecessary gossiping could be avoided.

In this case, each cached advertisement is treated separately and thus each entry of the cache is associated with an independent time handler. Other than broadcasting all entries at a time every gossiping round in pure gossiping model, different entries may have different scheduled time for gossiping and they are broadcasted separately. Algorithm 3 and 4 are extended from algorithm 1 and 2 in pure opportunistic gossiping model for dealing with an advertisement.

Algorithm 3: Receiving advertisement

```
when receive an advertisement ad {
entry ← cache.search(ad);
if entry ≠ NULL then
    interval ← delay caused by ad;
    entry.scheduledTime ←
    entry.scheduledTime + interval;
    discard ad;
else
    insert ad to cache;
    if cache.size > k then
        refresh all entries probabilities;
        drop the entry with the least probability;
}
```

Algorithm 4: Gossiping advertisement

```
when current time = entry.scheduledTime {
  refresh entry's probability;
  broadcast entry with the probability;
  entry.scheduledTime ← entry.scheduledTime + △t;
}
```

We call the pure *Opportunistic Gossiping* model with optimization mechanism (1) and (2) as *Optimized Gossiping-1* and *Optimized Gossiping-2* respectively. It is expected that *Optimized Gossiping-1* could be effective in un-sparse network while *Optimized Gossiping-2* works well in both sparse and dense networks. Since advertising mainly occurs in urban area where vehicles could be quite densely distributed, in this scenario, we adopt both optimized mechanisms and call pure gossiping model plus optimization mechanism (1) & (2) as *Optimized Gossiping*. However, if all peers within an advertising area accidentally leave without new peers entering, the advertisement will be lost and the issuer peer has to broadcast the advertisement again.

E. Advertisement Popularity

In the aforementioned *Gossiping* models, the advertising area shrinks with time elapsing as each advertisement is supposed to exist for only a limited duration. However, there may exist many advertisements issued from different issuers, and some advertisements may be more popular than others in a real scenario. Therefore, it is reasonable and necessary to consider user interests to rank each advertisement and then adjust the propagation parameters (i.e. duration D and radius R) of gossiping models. Consequently the more popular an advertisement is, the longer time it will exist for and the larger area it will be disseminated to.

To define the popularity of an advertisement, we adopt a rank function similar to the one used in [1] and [4]. The rank of an advertisement *ad* is simply determined by how many times it matches user interests. How to define interest is out of the cope of this paper, and we simply use keywords to represent a user's interests (notice that a user may have more than one interest). Assume the set of all users' interests is $I = \{I_1, I_2 \cdots I_n\}$, then the rank function is defined as stated in formula 5. The $Match()$ function compares the advertisement with $I_{i=0 \cdots n}$ and returns 1 if ad matches I_i, otherwise 0.

$$rank(ad) = \sum_{I_i \in I} Match(ad, I_i) \quad (5)$$

Although the ranking method is quite simple, how to figure out the rank correctly and efficiently in a distributed environment is not trivial. A naive method is to broadcast all users' interests within the network and each peer has to cache all interests. However, this method is very expensive to be implemented because cache resource is very scarce in mobile peers and extra broadcasting occupies too much bandwidth. Another approach is to embed the rank as a field in the advertisement message, and each time the advertisement matches a user's interest, the rank is increased by 1. Nevertheless, a peer may receive the same advertisement message (an advertisement may have many message copies) from different neighbors and a previously processed advertisement message may propagate back to the same peer later again, which causes duplicate increasing of the rank by the same peer. A potential solution is to record the *ID*s of all advertisements that passed through before, but this scheme also suffers from cache limitation. Besides, we can also append the *userID* to an advertisement message when it matches a user's interest, and then each user can figure out the rank by counting how many *userID*s are appended. Yet, this method may lead the size of an advertisement message to be too large especially when the advertisement is very popular.

Therefore, the key problem is how to get the number of interest matches without duplicate counting while preserving efficient use of cache and bandwidth. To tackle this problem, we develop a novel duplicate-insensitive scheme that utilizes FM algorithm [9] for generating rank. Our scheme records *userID*s by using only a set of fixed size bitmaps which are called *FM Sketch* that piggy-backed in the advertisement message. The length of each FM Sketch is L and there are F FM Sketches embedded, so the total extra size required is $L \times F$ bits (e.g. 32×32). Once a mobile peer receives an advertisement, it firstly checks whether the advertisement matches its interest by using the $Match()$ function. If yes, it hashes its *userID* to the F FM Sketches by using F independently generated hash functions. For example, if $hash(userID) = j, 1 \leq j \leq L$ then the j^{th} bit of the FM Sketch is set to be 1. Let $Min(FM)$ denote the least bit (from left) of a FM Sketch with value 0; if all bits are 1 then $Min(FM) = L$. To calculate the rank of the advertisement *ad*, it simply finds the $Min(FM)$ of each FM Sketch, and then the rank (i.e. the number of distinct *userID*s) is estimated by:

$$rank(ad) = \frac{1}{\varphi} 2 \sum_{i=1}^{F} min(FM_i)/F \quad (6)$$

In formula 6, $\varphi \approx 0.775351$ according to the approximate results in [9]. Similar to gossip-based aggregation in wireless network [19], all interested users' *ID*s are added to the FM Sketches in $O(\log N)$ gossiping rounds with high probability if we adopt pure gossiping (N is the number of peers). Let n be the accurate number of distinct users that add their *ID*s to the FM Sketches and $A = rank(ad)$ be the estimated number. For a given $\delta \in (0, 1)$ and F, if $L = O(logn + logF + log\delta^{-1})$, then the difference between n and A (i.e. $\mid A - n \mid$) is less than ϵn with probability at least $1 - \delta$, where $\epsilon = O(\sqrt{\frac{log\delta^{-1}}{F}})$ [20]. Therefore we are able to estimate the rank with comparatively high accuracy using just a small size of extra space in advertisement message. Notice that hashing an *userID* to a FM Sketch is actually a bit-wise OR operation of the hashing result and the existed FM Sketch which is entirely determined by the number of distinct users that are interested in the advertisement, and duplication does not affect FM Sketches.

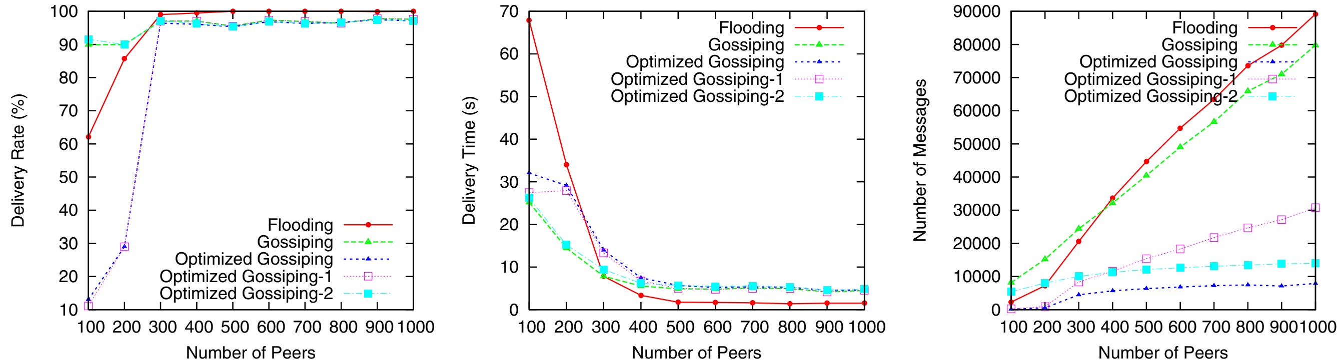
Based on FM Sketches, each peer within the advertising area can acquire the approximate popularity of an advertisement derived from the appended bitmaps in the advertisement message. As an advertisement is forwarded to more and more users, the rank increases gradually if it is popular, since more *userID*s are hashed and added to the message. After that, the pre-set advertising radius R and duration D are increased according to the rank. Our scheme works as following: on receiving an advertisement message, if it is of interest, a peer firstly computes the ranks of the advertisement before and after it hashes its $userID$ to the embedded FM Sketches. If the ranks are the same, which means this message has already been processed by this peer before (no FM Sketch change), the peer can skip the rank increasing step. Otherwise, the peer rises R and D respectively according to formula 7.

$$\begin{aligned} R &= R + \frac{1}{\log^2(rank+1)} \times \triangle R \\ D &= D + \frac{1}{\log^2(rank+1)} \times \triangle D \end{aligned} \quad (7)$$

Algorithm 5: Rank advertisement

```
input : Advertisement: ad
        FM Sketches: ad.FM_{1...F}
        Parameters: ad.R, ad.D
if Match(ad, interest) = 1 then
    rank_1 ← rank(ad);
    for i = 1 to F do
        j ← hash_i(userID);
        ad.FM_i[j − 1] ← 1;
    rank_2 ← rank(ad);
    if rank_2 > rank_1 then
        increase ad.R and ad.D;
```

$\frac{1}{\log^2(rank+1)}$ is used to limit the rate of increasing R and D, and these two parameters can not be increased infinitely even the advertisement is very popular since the spatial and temporal constraints. After k times of increasing, the new radius $R^{'} = R + \triangle R \sum_{rank=1}^{k} \frac{1}{\log^2(rank+1)}$ and the new duration $D^{'} = D + \triangle D \sum_{rank=1}^{k} \frac{1}{\log^2(rank+1)}$. So even an advertisement message's rank gets increased every gossiping round, it eventually expires at time $t^{'} = k \triangle t$ where k satisfies condition: $k \triangle t > D + \triangle D \sum_{rank=1}^{k} \frac{1}{\log^2(rank+1)}$.



(a) (b) (c)

Fig. 7. Performance in different network sizes

For example, if $D = 1800, \triangle t = 5$ and $\triangle D = 0.01D$, the age $t^{'}$ is larger than $D^{'}$ when $k = 443$ at most and then the advertisement message expires. Algorithm 5 presents the process of adjusting propagation parameters R and D for satisfying requirement 3) of the propagation model for instant advertising. This algorithm provides an enlarging mechanism for rising the size of advertising area and the survival time of an advertisement. When an advertisement is received and it is not in the cache, this algorithm is invoked by the gossiping model. The rank is calculated twice using the FM Sketches appended in the advertisement message before and after the hashing *userID* operations respectively. If the rank goes up, R and D are increased using formula 7.

IV. Experiments

In this section, we evaluate our approaches through simulation. The Flooding, Gossiping and Optimized Gossiping methods are all implemented as protocols in Network Simulator *NS-2*[1] which is a discrete event simulator widely adopted in networking research area. We test the performance of these methods in a $5000m \times 5000m$ mobile scenario with mobile trajectories generated by using the Random Waypoint mobility model[2]. In this model each moving peer is allocated at a random position of the simulation area and it moves at constant speed in a straight line to another random position, where it pauses for a while and then moves again to another random position; and so on. All mobile peers communicate in an unstructure way by 802.11 protocol and the transmission range is 250 meters. All advertisements are in text format grouped by advertisement type (e.g. petrol, traffic).

The main metrics we adopt are:

- *Delivery Rate*: defined as the percentage of mobile peers that receive the advertisement successfully while passing through the corresponding advertising area, which is equal to $\frac{\textit{number of peers got the advertisement}}{\textit{number of peers passed through the advertising area}}$;
- *Delivery Time*: defined as the duration from a peer entering the advertising area until it receives the advertisement. This metric is for measuring how soon the advertisement could be delivered to new peers. Basically, the shorter the delivery time is, the better the performance is as user can make decision earlier when approaching the advertisement issuing position;
- *Number of Messages*: defined as the total number of messages generated by the whole network. It reflects the whole network traffic, and we aim to reduce this number so as to save wireless bandwidth and relieve network congestions.

[1]http://www.isi.edu/nsnam/ns/
[2]http://icawww1.epfl.ch/RandomTrip/

TABLE II
Parameter Setting

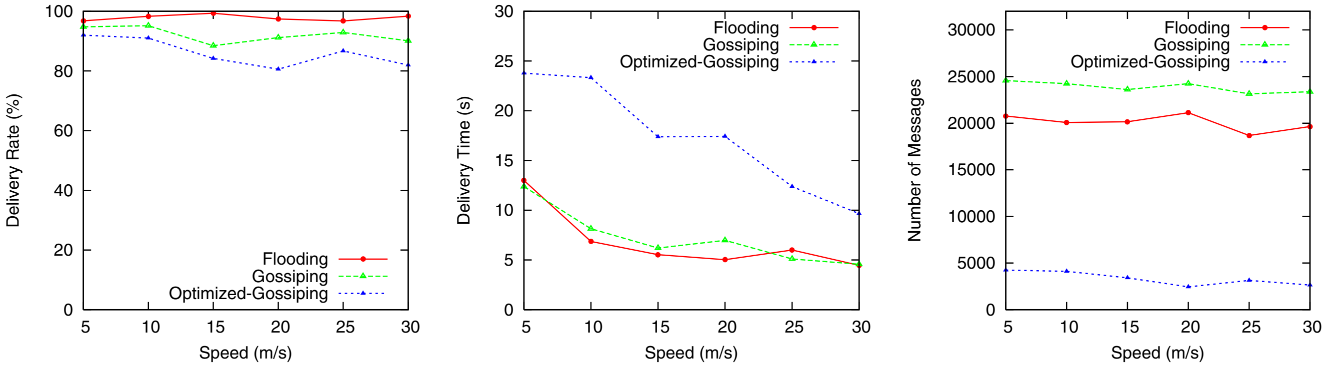
Name	value
Simulation Time	2000 seconds
R	1000 meters
D	1800 seconds
α, β	0.5
Gossiping Round Time	5 seconds
DIS	$R/4$

All the metrics above are collected during the time interval D (a life cycle) of an advertisement. Ideally, *Delivery Rate* should be kept close to 100%, whereas *Delivery Time* and *Number of Messages* should be reduced as much as possible.

A. Performance Comparison

In this subsection, we study the performance of our approaches in different network sizes and at different motion speeds. We assume there is only one advertisement issued at position $(2500, 2500)$, which is the center of the simulation area. Other parameter settings are indicated in Table II.

First of all, we compare *Delivery Rate* of Flooding, Gossiping and Optimized Gossiping with network size varying from 100 peers to 1000 peers (i.e. the density of mobile peers are from 4 peers per km^2 to 40 peers per km^2). All mobile peers move at an mean speed of $10m/s$ with a delta of $5m/s$. As illustrated in figure 7(a), when the network is dense enough ($>$ 300 peers), all the three methods are efficient. Flooding is the best (*Delivery Rate* $\approx 100\%$), while



(a) (b) (c)

Fig. 8. Performance at different motion speeds

pure Gossiping and Optimized Gossiping have nearly the same *Delivery Rate* that is just a little lower than that of Flooding. However, when the network is sparse (<300 peers), both Flooding and Optimized Gossiping degrade significantly while pure Gossiping approach still keeps good *Delivery Rate* ($>90\%$) even when the network becomes very sparse. That is because mobile peers are usually too far away from each other and thus outside the transmission range in a sparse network. Consequently, the network becomes disconnected and partitioned, which blocks flooding messages from being further relayed. On the contrary, pure Gossiping caches the advertisement and benefits from the *Store & Forward* strategy and thus maintains high quality *Delivery Rate*. Optimized Gossiping also does not perform well because of Optimization Mechanism (1) as discussed in the next subsection.

Similarly, in term of *Delivery Time*, pure Gossiping outperforms the other two approaches in sparse network because new entering peers need more gossiping rounds to know about the advertisement in Flooding and Optimized Gossiping methods. When network size is larger than 300 peers, nevertheless, the performance of these there methods are close (all less than 10 seconds), as presented in figure 7(b). While achieving similar performance to Flooding and pure Gossiping in dense network ($>$ 300 peers), Optimized Gossiping reduces the number of messages by nearly an order of magnitude. From figure 7(c), we can see that the number of messages produced by Optimized Gossiping is only 8.85% and 9.89% of that generated by Flooding and pure Gossiping respectively when network size $=1000$ peers. Since network bandwidth is very precious in wireless network, we conclude that Optimized Gossiping greatly improves the performance of advertising over Flooding and pure Gossiping.

Furthermore, we also test the effect of motion speed of mobile peers on the performance of Flooding, Gossiping and Optimized Gossiping. As shown in the figure 8(a) and 8(c), motion speed of mobile peers has limited impact on *Delivery Rate* and *Number of Messages* for all three methods. These two metrics keep nearly stable with a little fluctuation when motion speed increases from $5m/s$ to $30m/s$ (network size is

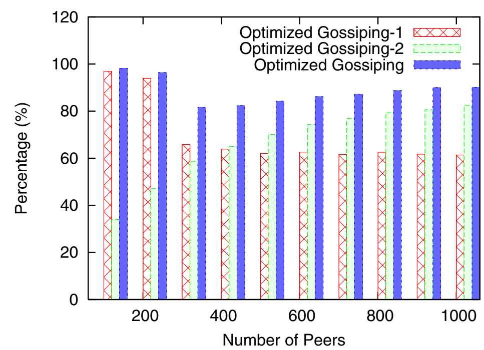


Fig. 9. Percentage of messages reduced by mechanism (1) and (2)

set to 300 peers). In contrast, the *Delivery Time* interestingly drops (see figure 8(b)) while motion speed increases. That is because higher speed helps in increasing the speed of carrying advertisement copies to other locations of the advertising area and thus increases the speed of advertisement dissemination especially when the network is not dense enough. Nonetheless, Optimized Gossiping always outperforms the other two methods significantly in term of *Number of Messages*.

B. Gossiping Optimization

Another observation from figure 7(a), 7(b) and 7(c) is that Optimized Gossiping-2 generates much smaller number of messages than pure Gossiping, while it still has nearly the same performance to pure Gossiping in terms of *Delivery Rate* and *Delivery Time* in both dense and sparse networks. That means Optimization Mechanism (2) is very effective in reducing redundant gossiping without affecting the quality of advertisement propagation. In contrast, Optimized Gossiping-1 performs worse than Optimized Gossiping-2 on *Deliver Rate* and *Delivery Time* in sparse network ($<$ 300 peers) because Optimization Mechanism (1) limits the area where peers can gossip with high probability to a comparatively small annular region. Therefore, if peer distribution is sparse, many new entering peers miss the 'gossip' when going through the annular region. That is why the performance of Optimized

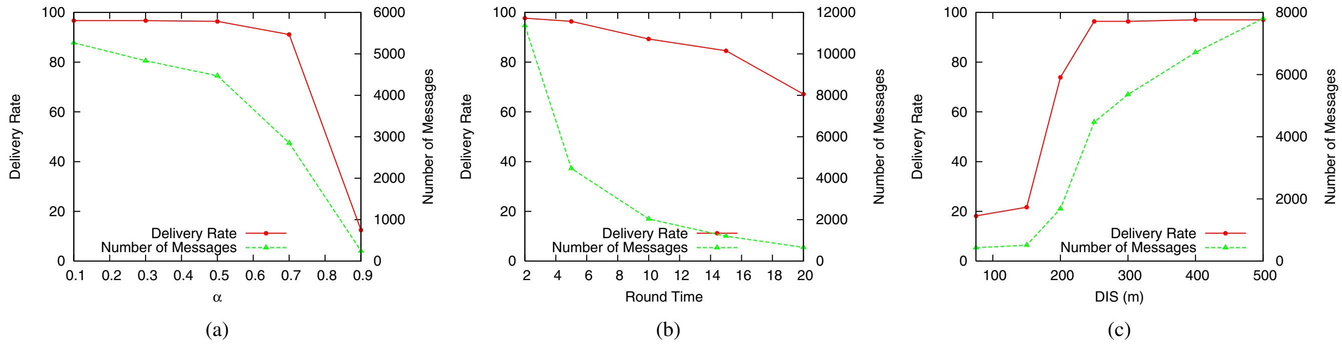


Fig. 10. Tuning parameters

Gossiping that integrates both optimization mechanism (1) and (2) is worse than pure Gossiping in sparse network. However, Optimized Gossiping-1 helps greatly in reducing the number of messages.

In the following, we further have a clearer performance comparison on the *Number of Messages* between two optimization mechanisms. As illustrated in figure 9, each bar represents the percentage of messages reduced from pure Gossiping when each method is applied on pure Gossiping. As network density increases, the message reduction power of mechanism (1) decreases while that of mechanism (2) goes up. When the network becomes dense enough (> 300 peers), mechanism (2) turns to be more effective than mechanism (1). Although mechanism (1) reduces more than 90% of messages in sparse network (< 300 peers), it reduces not only redundant but also necessary gossiping messages, which is the reason of low *Delivery Rate* in sparse network as presented in the previous subsection. Yet, mechanism (1) provides stable message reduction power ($> 60\%$ reduction) in dense network, and Optimized Gossiping achieves more than 80% message reduction while integrating mechanism (1) and (2) together.

Therefore, given the better performance of Optimized Gossiping-2 on *Delivery Rate* and *Delivery Time* in sparse network, it is suggested Optimized Gossiping-2 is used to ensure quality delivery in sparse network. On the other hand, when the network is dense, Optimized Gossiping which integrates both mechanism (1) and mechanism (2) is advised to have a small number messages in the network.

C. Impact of Tuning Parameters

The tuning parameters: α, β, *Gossiping Round Time* and DIS have different impacts on our Optimized Gossiping model. α determines the distribution of forwarding probability (i.e. how soon the probability drops). Similarly, β determines the decay rate of advertising radius R that impacts the survival time of an advertisement. *Gossiping Round Time* represents the frequency of advertisement forwarding and hence has great impact on *Number of Messages*. DIS limits the area where to gossip with high probability, and thus our model tends to be pure gossiping if $DIS \approx R$ while the model would has very low *Delivery Rate* or even fails if DIS is close to 0.

TABLE III

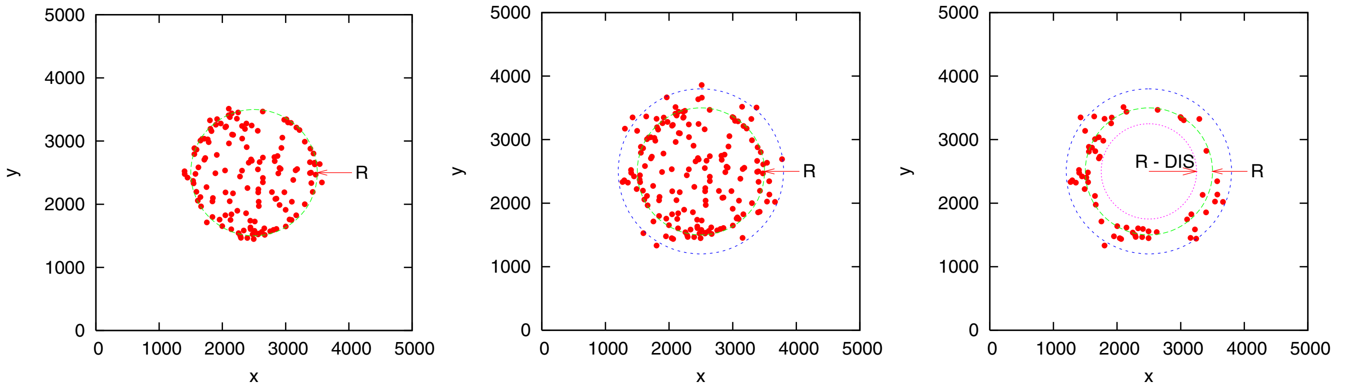
PARAMETER SETTING

Name	value
Simulation Time	2000 seconds
R	1000 meters
D	1800 seconds
Speed	10m/s ± 5m/s
Network size	300 peers

As β has negligible impact on our performance metrics (The *Number of Messages*, *Delivery Rate* and *Delivery Time* drop by 50, 0.012 and 0.044 respectively when β increases from 0.1 to 0.9), we only study α, *Gossiping Round Time* and DIS in the following. Experiment settings are listed in Table III.

Firstly, we set the *Gossiping Round Time* $\triangle T = 5s$ and $DIS = 250m$, and increase α from 0.1 to 0.9. Figure 10(a) illustrates the changes of *Delivery Rate* and *Number of Messages* as α rises. When $\alpha < 0.5$ the *Delivery Rate* keeps at a high value ($> 96\%$) steadily, and decreases slowly when $0.5 < \alpha < 0.7$, followed by a sharp drop when $\alpha > 0.7$. At the same time, the *Number of Messages* drops gradually from more than 5000 to lower than 300. Considering that *Delivery Rate* is more critical in our application and *Number of Messages* is already reduced to a quite low level comparing with that produced by pure Gossiping and Flooding, so we choose $\alpha = 0.5$ in our experiment. For a similar reason, we choose *Gossiping Round Time* $= 5s$ as it produces a high *Delivery Rate* while the *Number of Messages* is reduced to a comparatively low level (refer to figure 10(b), $\alpha = 0.5$, $DIS = 250m$). The trends of *Delivery Rate* and *Number of Messages* caused by different DIS is reversed to that caused by α and $\triangle t$. Let $\alpha = 0.5$ and $\triangle t = 5s$. According to figure 10(c), while the DIS value is low ($< 200m$), many new peers that pass through the advertising area miss the advertisement and therefore a very low *Delivery Rate* is caused. When the DIS increases to $250m$, the *Delivery Rate* grows to more than 96%. After that, further increase in DIS helps little in increasing the *Delivery Rate* while the *Number of Messages* keeps growing steadily. So we choose $250m$ to be the DIS value.

In term of *Delivery Time*, as long as it is less than the least



(a) (b) (c)

Fig. 11. Advertisement distribution

TABLE IV
DELIVERY TIME

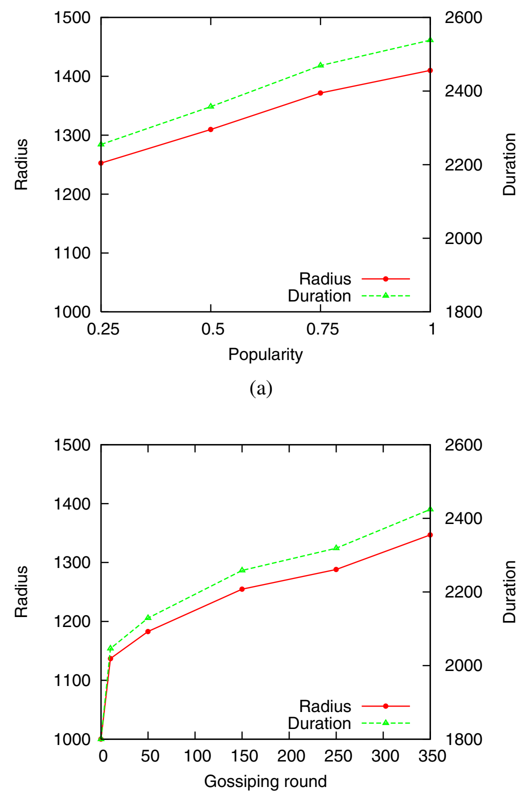
α	0.1	0.3	**0.5**	0.7	0.9
Delivery Time	13.62s	14.61s	**13.97s**	25.42s	23.81s
$\triangle T$	2	**5**	10	15	20
Delivery Time	8.13s	**13.97s**	26.65s	34.18s	36.05s
DIS	75	200	**250**	300	400
Delivery Time	18.84s	32.16s	**13.97s**	12.56s	9.83s

time needed to arrive at the issuing location (i.e. $\frac{Radius}{V_{max}} = \frac{1000m}{15m/s} \approx 66.6s$), it does not have too much impact on performance and thus is not so critical. As shown in Table IV, when $\alpha = 0.5$, $\triangle T = 5s$ and $DIS = 250m$, the *Delivery Time* is round $14s$ which is comparatively good.

D. Impact of User Interest

In this subsection, we examine the enlarging mechanism based on advertisement popularity. The parameter setting is the same as that in Table III, and we choose $\alpha = \beta = 0.5, DIS = 250m, \triangle t = 5s$ here. $\triangle R$ and $\triangle D$ used in formula 7 are set to be $R/20$ and $D/20$ respectively.

First of all, we study the distribution of an advertisement that with and without users be interested in when using the pure Gossiping model. If an advertisement is of no interest at all, it eventually spreads to the pre-set advertising area with radius $R = 1000m$ and then expires. Figure 11(a) illustrates the distribution of an advertisement at middle age ($= 900s$). We can see that most mobile peers that hold the advertisement (represented by a dot) distribute within the circle (pres-set advertising area). In contrast, if the advertisement is popular (we set $1/2$ randomly chose users be interested in the advertisement), it propagates to a larger area with a new radius approximates to $1250m$ because interest matches enlarge both radius R and duration D as shown in figure 11(b) (the label R indicates the original radius). When we change the advertising model to be Optimized Gossiping, many advertisement messages are reduced consequently and it leads to a comparatively sparse distribution. As shown in



(b)

Fig. 12. Radius and duration

the figure 11(c), advertisement copies are mainly distributed within the annular area.

It is very straight forward that the number of matches of user interests determines how large the advertising area can be enlarged and how long the advertisement can exist. This could also be concluded from figure 12(a), in which the radius and duration of the advertising area at age $t = 1795s$ increase steadily when the popularity (represented by percentage of users that be interested in the advertisement) grows from 25% to 100%. Here, we use the average value of R and D from all advertisement message copies, as different advertisement copies may have different R and D since they are processed separately. Besides, how soon a peer can learn about others' interests also affects the enlarging mechanism, and this can be reflected from how fast R and D increase by time. Optimistically, a peer can learn about others' interests in $O(\log N)$ gossiping rounds [19] if using the pure gossiping model. When we adopt the optimization mechanisms, the interest propagation speed should be comparatively lower because many messages are reduced. However, as we can see from figure 12(b), the increasing speed of R and D is still quite high. During the first 10 gossiping rounds, R and D rise dramatically and then keep growing stably during the rest survival time until the advertisement expires.

V. Conclusion

In this paper, we propose a new application scenario for instant advertising in a Mobile Peer-to-Peer Network, and provide several advertisement propagation methods including Flooding, pure Gossiping and Optimized Gossiping for disseminating advertisements with spatial and temporal constraints. We aim to provide high *Delivery Rate* of advertisement while keeping low *Delivery Time* and *Number of Messages*. The Opportunistic Gossiping model, optimization mechanisms, advertisement popularity as well as ranking algorithm are discussed in detail. According to our simulation results, the Optimized Gossiping-2 approach achieves high *Delivery Rate* as good as pure Gossiping and flooding in either sparse or dense network, while generates much lower *Number of Messages*. For un-sparse network, the Optimized Gossiping (Optimized Gossiping-1 plus Optimized Gossiping-2) further reduces the *Number of Messages* to less than $1/10$ of that produced by pure Gossiping and Flooding, and the *Delivery Rate* is still kept high ($> 96\%$).

References

[1] O. Wolfson, B. Xu, H. Yin, and H. Cao, "Search-and-discover in mobile p2p network databases," in *Proc. of ICDCS*, 2006, pp. 1–9.

[2] P. Costa, D. Frey, M. Migliavacca, and L. Mottola, "Towards lightweight information dissemination in inter-vehicular networks," in *Proc. of VANET*, 2006, pp. 20–29.

[3] M. Caliskan, D. Graupner, and M. Mauve, "Decentralized discovery of free parking places," in *Proc. of VANET*, 2006, pp. 30–39.

[4] O. Wolfson, B. Xu, H. Yin, and H. Cao, "Searching local information in mobile databases," in *Proc. of ICDE*, 2006, pp. 136–136.

[5] M. Lupur, J. Li, B. Ooi, and S. Shi, "Clustering wavelets to speed-up data dissemination in structured p2p manets," in *Proc. of ICDE*, 2007, pp. 386–395.

[6] P. T. Eugster, P. A. Felber, R. Guerraoui, and A.-M. Kermarrec, "The many faces of publish/subscribe," *ACM Computing Surveys*, vol. 35, no. 2, pp. 114–131, 2003.

[7] R. Zhang and Y. Hu, "Hyper: A hybrid approach to efficient content-based publish/subscribe," in *Proc. of ICDCS*, 2005, pp. 427–436.

[8] Y. Diao, S. Rizvi, and M. J. Franklin, "Towards an internet-scale xml dissemination service," in *Proc. of VLDB*, 2004, pp. 612–623.

[9] P. Flajolet and G. N. Martin, "Probabilistic counting algorithms for data base applications," *Journal of Computer and System Sciences*, vol. 31, no. 2, pp. 182–209, 1985.

[10] B. Xu, A. Ouksel, and O. Wolfson, "Opportunistic resource exchange in inter-vehicle ad-hoc networks," in *Proc. of MDM*, 2004, pp. 4–12.

[11] A. Sistla, O. Wolfson, and B. Xu, "Opportunistic data dissemination in mobile peer-to-peer networks," in *Proc. of SSTD*, 2005, pp. 346–363.

[12] J. Considine, F. Li, G. Kollios, and J. Byers, "Approximate aggregation techniques for sensor databases," in *Proc. of ICDE*, 2004, pp. 449–460.

[13] S. Nath, P. B. Gibbons, S. Seshan, and Z. Anderson, "Synopsis diffusion for robust aggregation in sensor networks," *ACM Transactions on Sensor Networks*, vol. 4, no. 2, pp. 1–40, 2008.

[14] H. Wu, C. Wang, and N.-F. Tzeng, "Novel self-configurable positioning technique for multihop wireless networks," *IEEE/ACM Transactions on Networking*, vol. 13, no. 3, pp. 609–621, 2005.

[15] S. Boyd, A. Ghosh, B. Prabhakar, and D. Shah, "Gossip algorithms: design, analysis and applications," in *Proc. of INFOCOM*, vol. 3, 2005, pp. 1653–1664.

[16] S. Kashyap, S. Deb, K. V. M. Naidu, R. Rastogi, and A. Srinivasan, "Efficient gossip-based aggregate computation," in *Proc. of PODS*, 2006, pp. 308–317.

[17] J. Zhao and G. Cao, "Vadd: Vehicle-assisted data delivery in vehicular ad hoc networks," in *Proc. of INFOCOM*, 2006, pp. 1–12.

[18] A. Vahdat and D. Becker, "Epidemic routing for partially-connected ad hoc networks," in *Technical Report CS-200006, Duke University*, 2000.

[19] J.-Y. Chen, G. Pandurangan, and D. Xu, "Robust computation of aggregates in wireless sensor networks: Distributed randomized algorithms and analysis," *IEEE Transactions on Parallel and Distributed Systems*, vol. 17, no. 9, pp. 987–1000, 2006.

[20] X. Lin, Y. Yuan, Q. Zhang, and Y. Zhang, "Selecting stars: The k most representative skyline operator," in *Proc. of ICDE*, 2007, pp. 86–95.